Simulation Methodology for LiDAR on Chip

Simulation and Design Using RSoft Tools

Note: The purpose of this application note is

by designers to assist them in designing photonic devices. This document is not intended to create a novel LIDAR-on-chip design.

Outline

Introduction

Overall Design and Simulation Strategy

Individual Component Simulation

- Power Splitter
- Thermal-Optical Phase Shifter
- Emitting Gratings

Conclusion

Introduction

LIDAR (Light Detection And Ranging) is a critical device for self-driving cars

- Bulky and clumsy, with 64 lasers
- Contains moving parts
- Very expensive, costs more than the car itself

Introduction

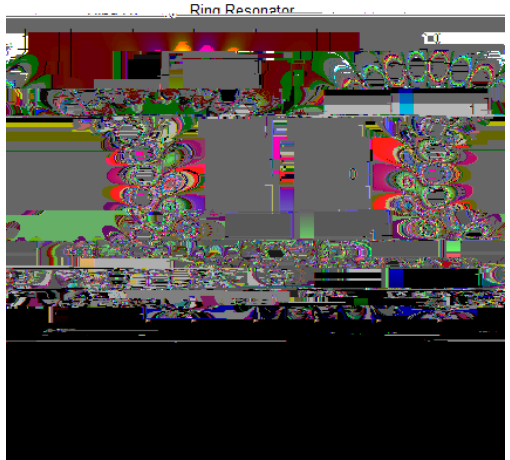
Design optimization is essential to make an on-chip LIDAR practical for the commercial market

- Minimize insertion loss and increase output optical power
- Increase the beam steering range
- Narrow the emitting beam
- Reduce the size

Reliable simulation tools are critical to achieve design tasks

- Reduce development time and cost
- Allows design testing/modification without prototype construction

RSoft provides a variety of simulation tools for optimizing design of various components



Overall Design and Simulation Strategy

Structure by Gent University & IMEC

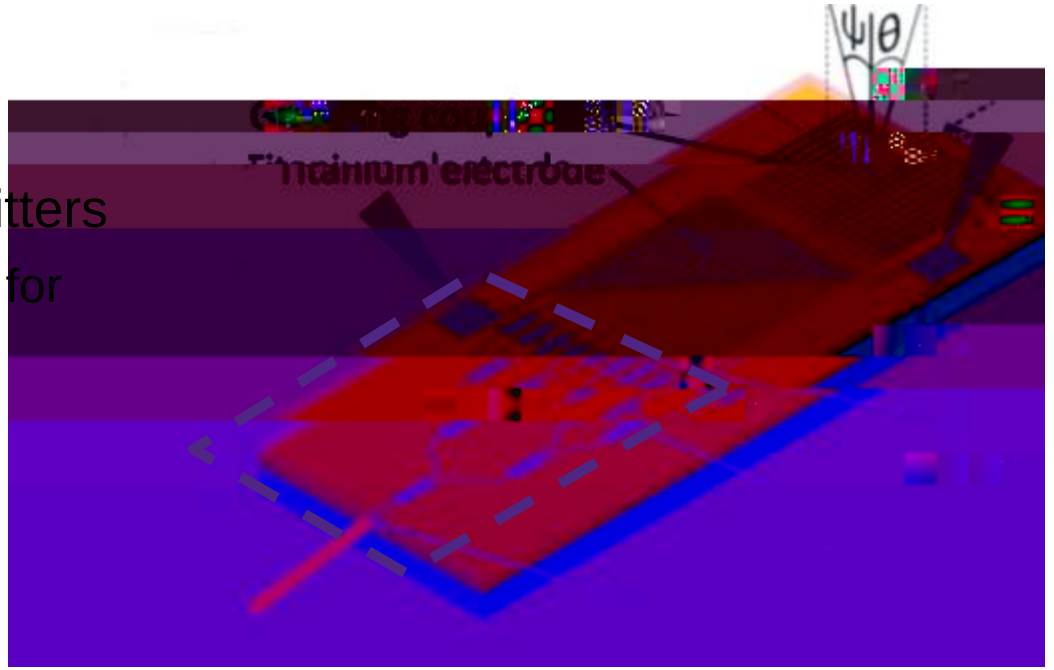
No single simulation tool can solve the complex problem

Complicated design layout can be achieved in RSoft

Power Splitters

Design utilizes cascaded 1x2 power splitters

Can potentially use 1x2 MMI or Y-Branch for power splitting



1x2 MMI

Complex, several parameters to optimize

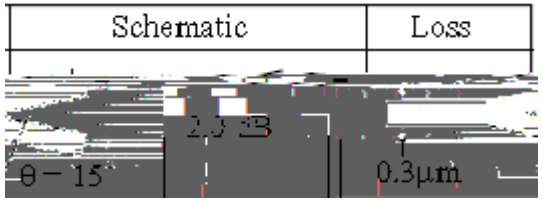
Wavelength sensitive and limited bandwidth

Polarization dependent

Low insertion loss (~0.3dB)

Robust

Y-Branch



Simple, 2 S-bends

Broadband

Polarization independent

High insertion loss (~2dB)

Less tolerant to asymmetric input

Sakai, Atsushi, Tatsuhiko Fukazawa, and Toshihiko Baba. "Low loss ultra-small branches in a silicon photonic wire waveguide." *IEICE Transactions on Electronics*

1x2 MMI

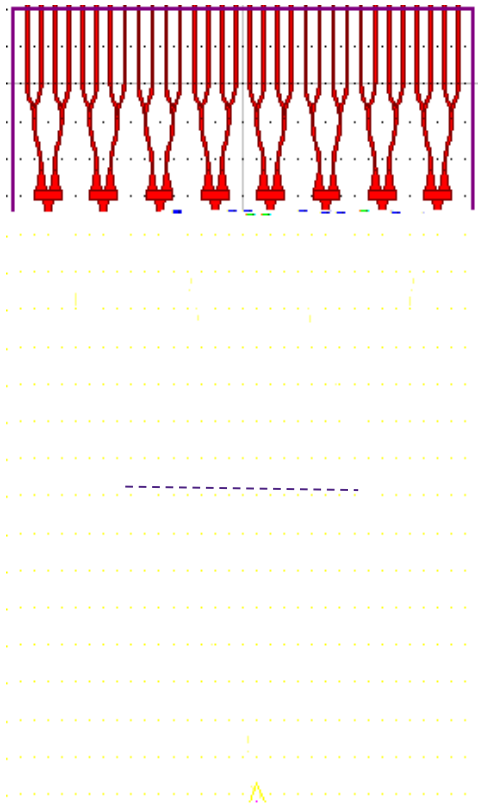
There are several parameters to optimize

- MMI width & length
- Taper length & width
- Separation is fixed at 2μm

Optimized structure by 2D-EIM BeamPROP

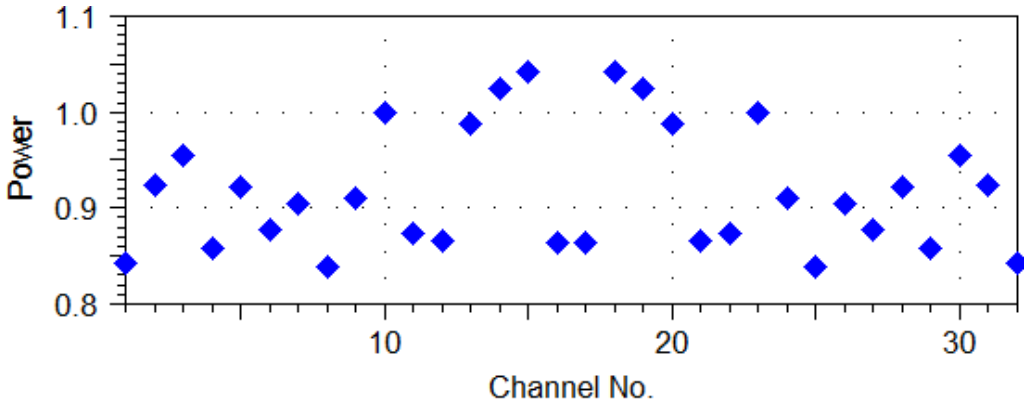
1x32 Power Splitter

Cascaded 1x2 splitters



BeamPROP simulation

Monitored power and phase



Thermal-Optical Phase Shifter

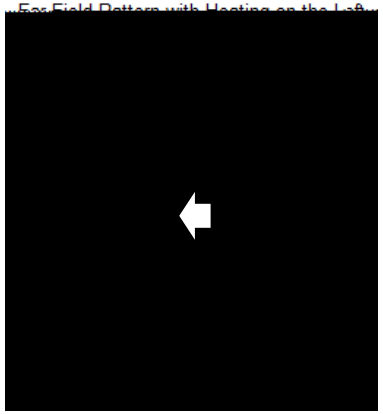
Working mechanism

Silicon is a thermally sensitive material with thermal-optical coefficient:

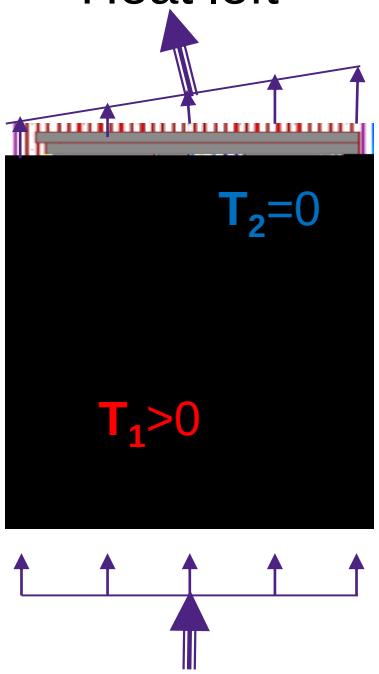
—

Heating the waveguide array unequally creates phase delays among each other

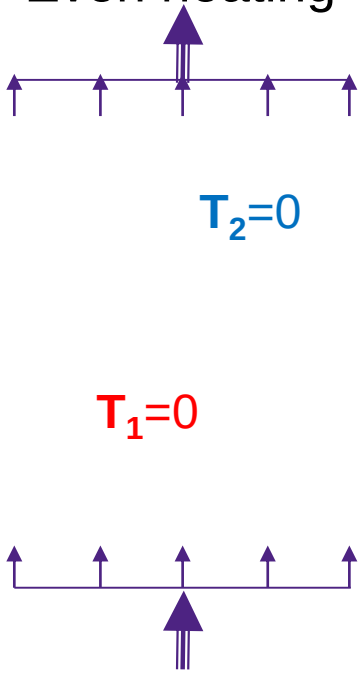
Because of the phase delay, the emerging light will be steered to one side

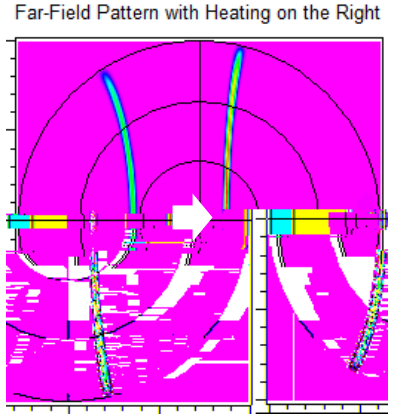


Heat left

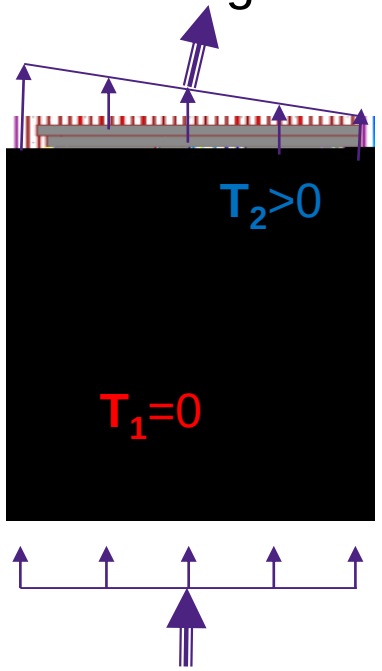


Even heating





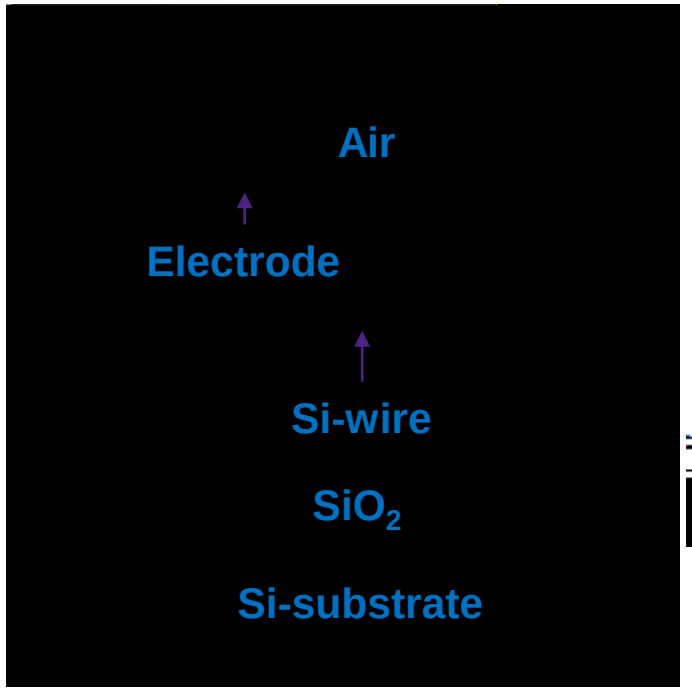
Heat right



Thermal-Optical Phase Shifter

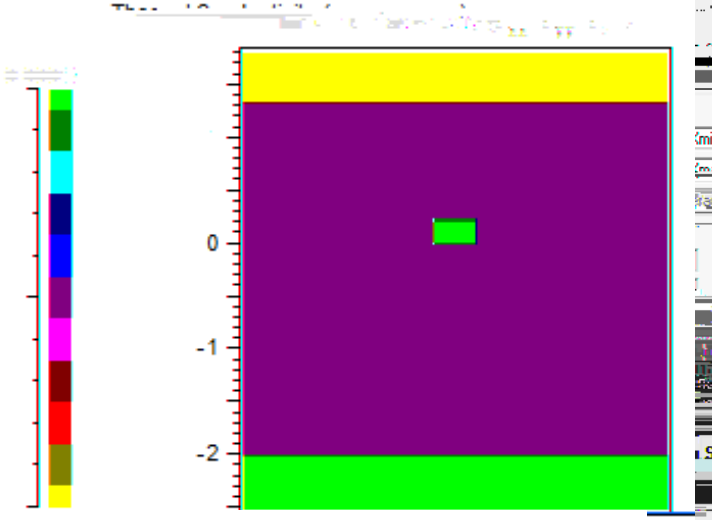
Thermal solver

Configuration

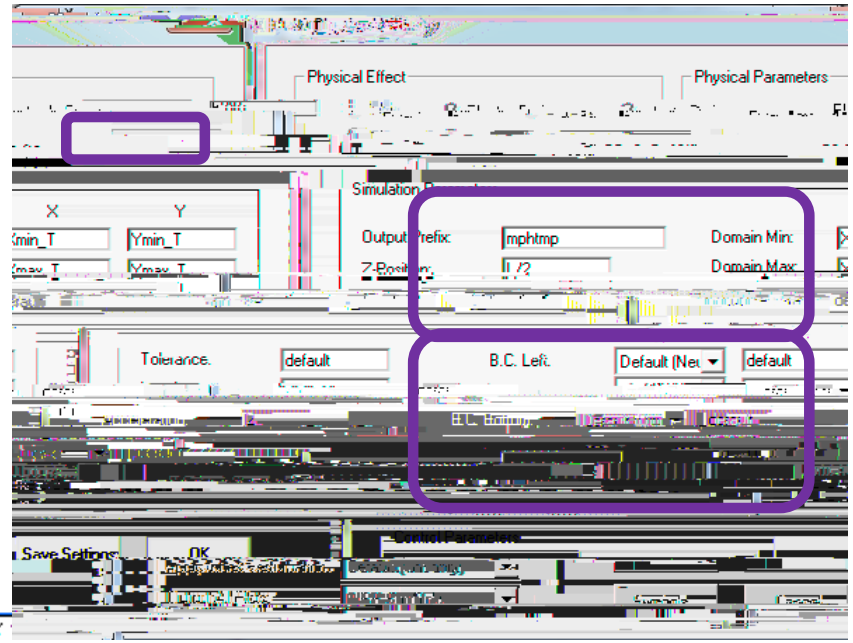


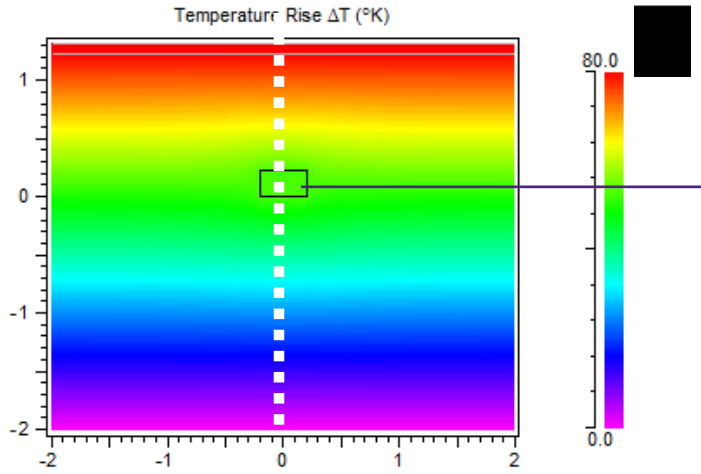
Tip: For better convergence, exclude air in computational window

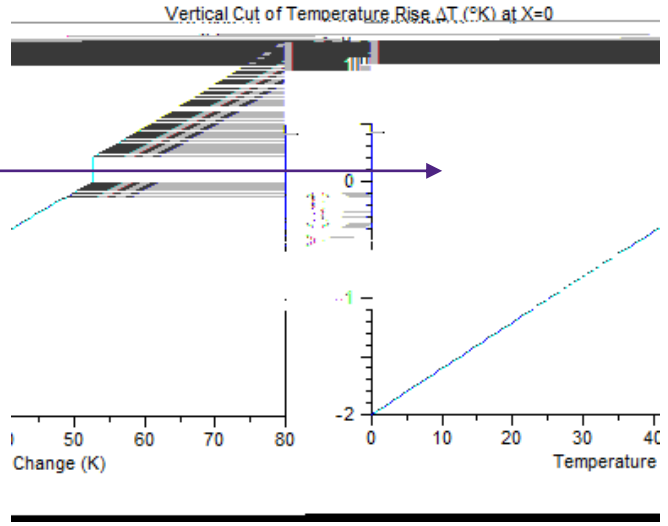
Thermal conductivity



RSoft Multiphysics Solver settings

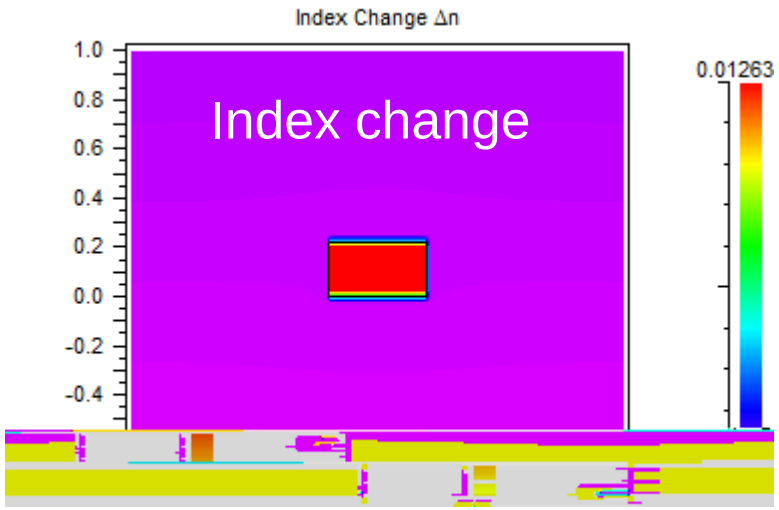


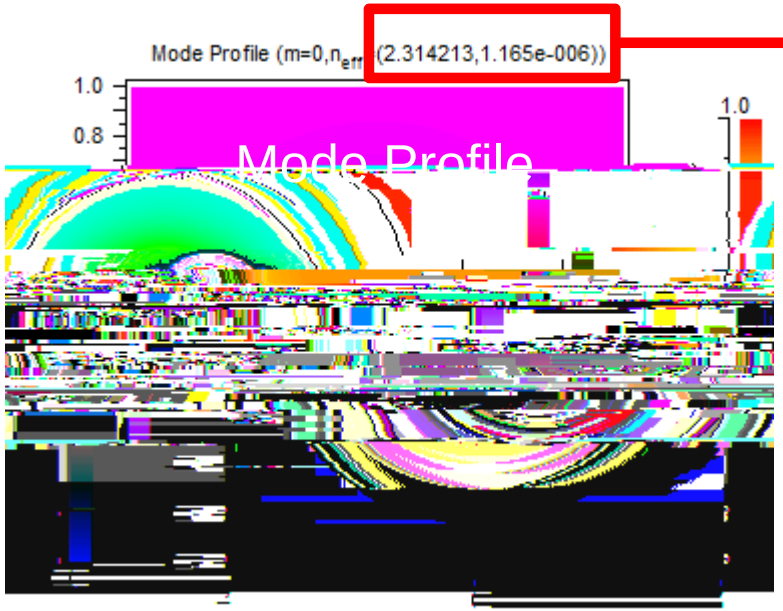




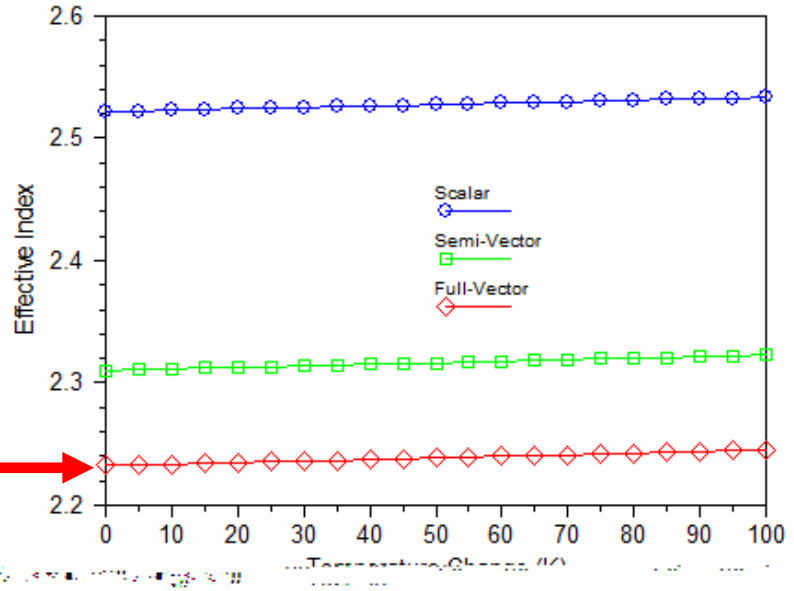
Thermal-Optical Phase Shifter

Thermal-Optics

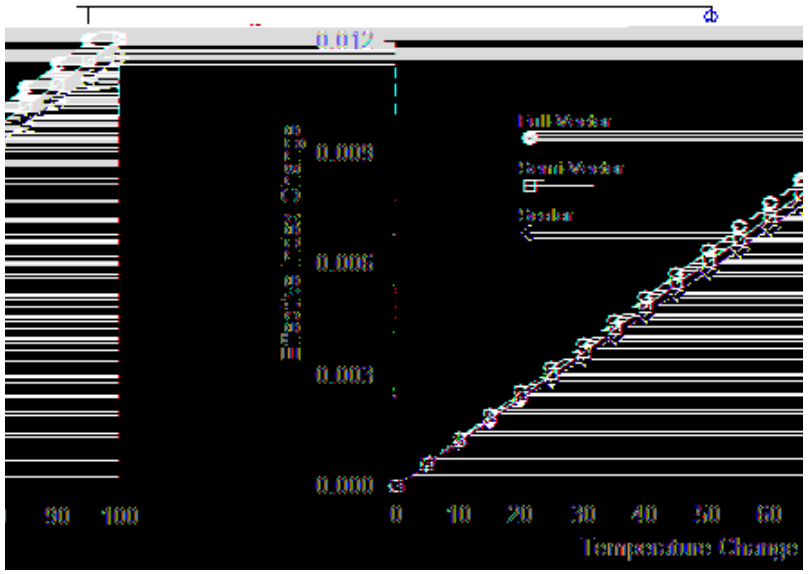




Effective index



Change in effective index



Summary:

Effective index of propagation mode is different based on scalar, semi-vector, or full-vector mode calculation

The index change vs temperature is similar for three cases

Semi-vector or even scalar mode propagation can be used for efficient and reliable calculation

Thermal-Optical Phase Shifter

Phase shift: = —

effective index change, wavelength,

L device length

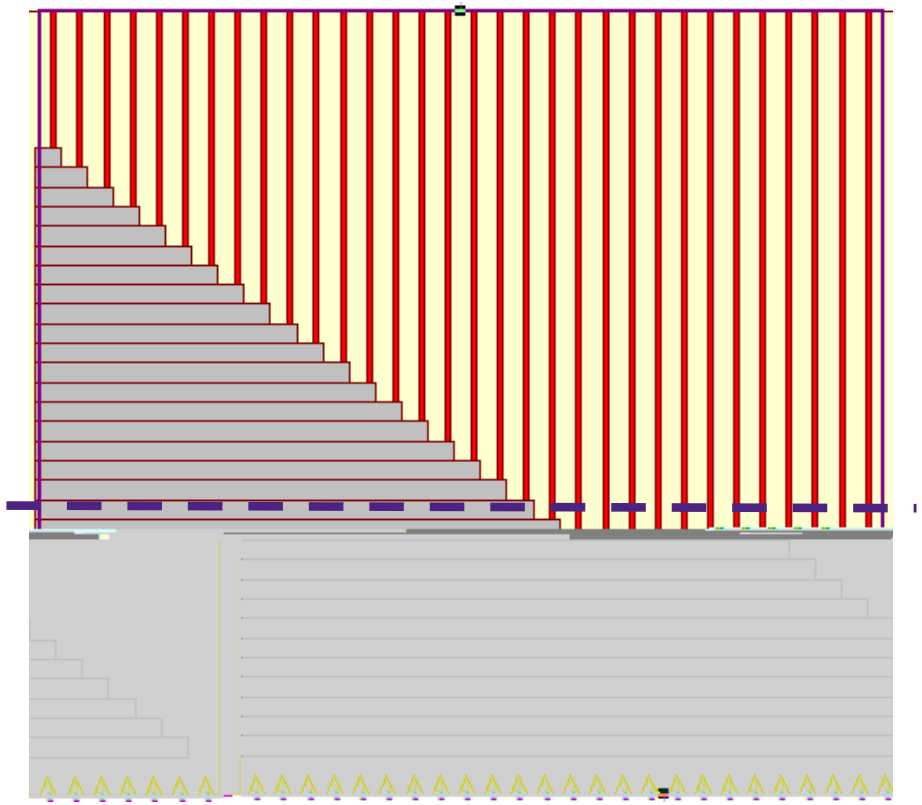
Device length to acheve phase shift:

= ———

Thermal-Optical Phase Shifter

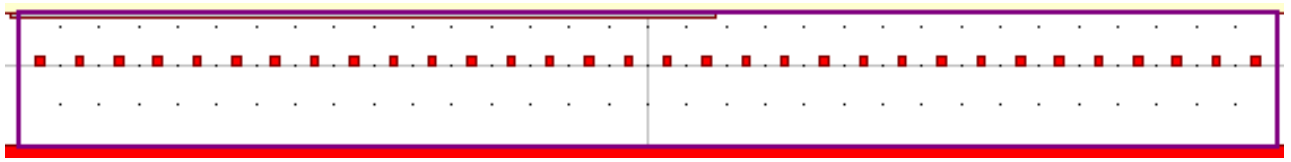
Phase Arrays Thermal-Optic Solver

Top view

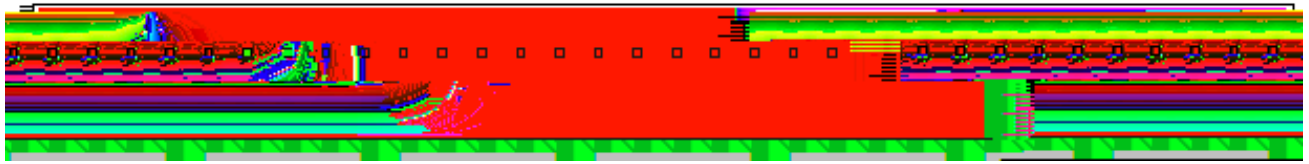


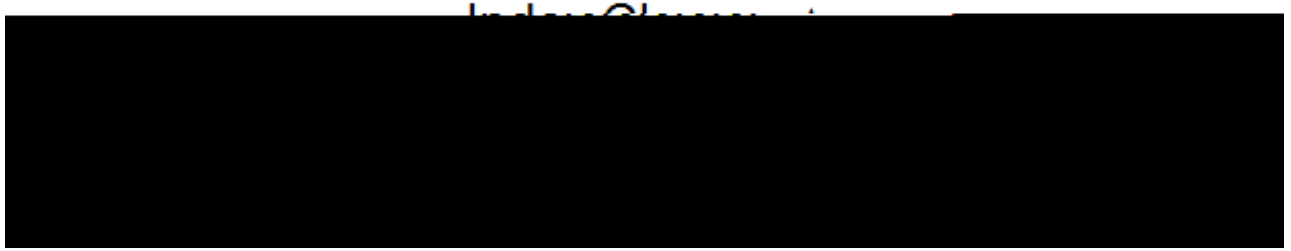
Triangle-shaped heaters give different phase shifts for different waveguides

Cross-section view



Temperature Rise ΔT (°K)

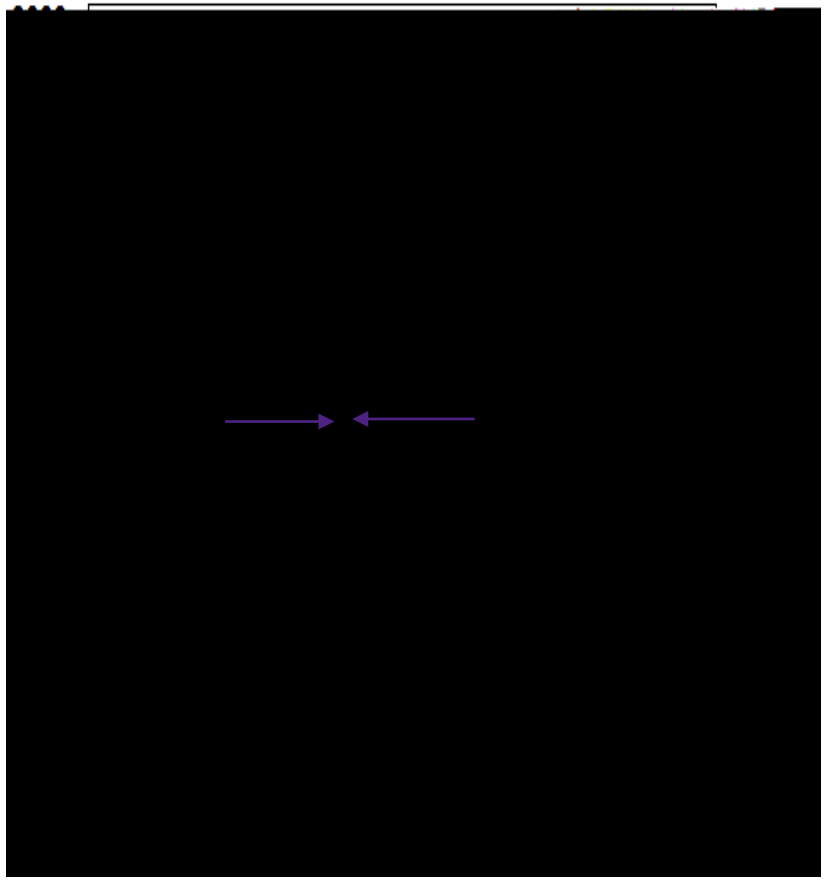




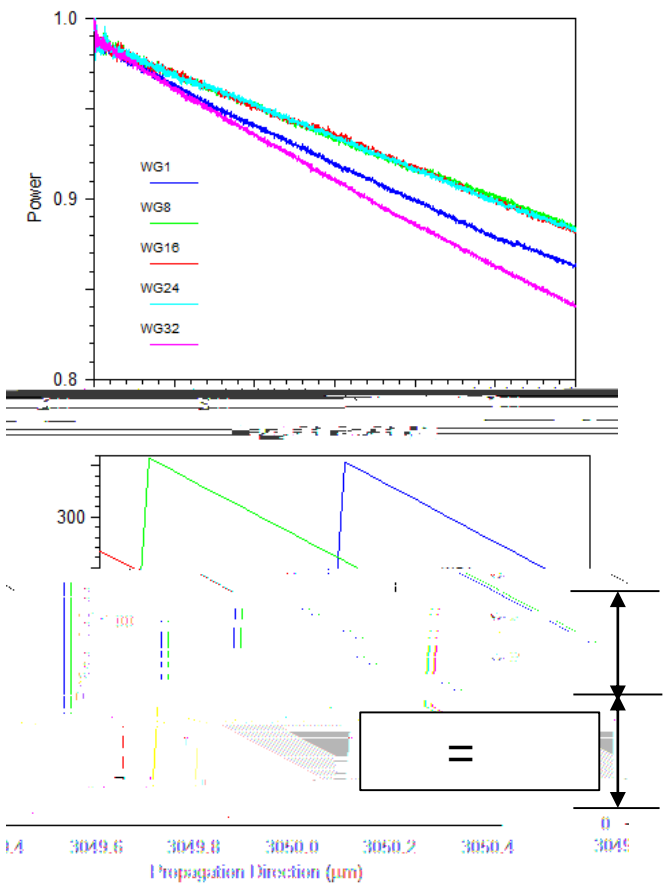
Thermal-Optical Phase Shifter

Phase Arrays Optical Simulation

BeamPROP traces beam input from each waveguide

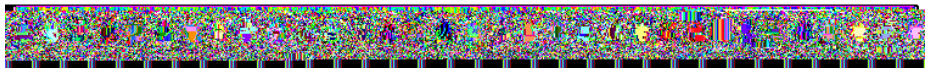


Both power and phase of each waveguide are monitored

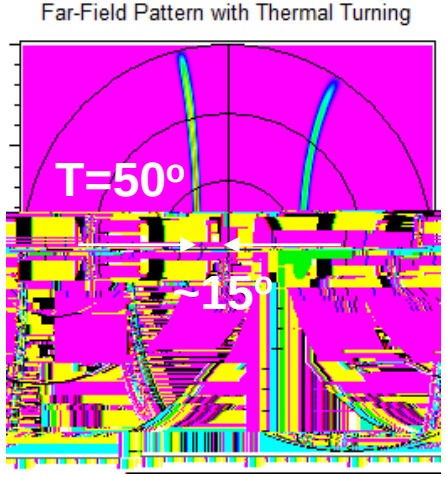


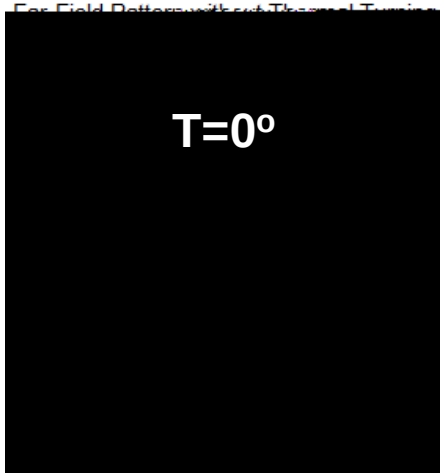
Both amplitude and phase can be recorded at the end of the waveguides

Phase Profile at the End



Far-field from edge can be calculated





Thermal-Optical Phase Shifter

Emitting Gratings

Width Gratings

- Easy process, one-step etching
- Easy to apodize to emit light evenly

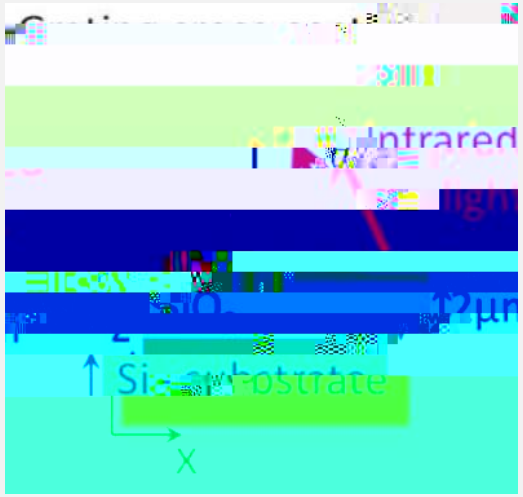
MIT

Poulton, Christopher V., et al. "Optical phased array with small spot size, high steering range and grouped cascaded phase shifters." *Integrated Photonics Research, Silicon and Nanophotonics*. Optical Society of America, 2016.

Shallow Gratings

- Complex process, two-step etching
- Difficult to apodize

Ghent

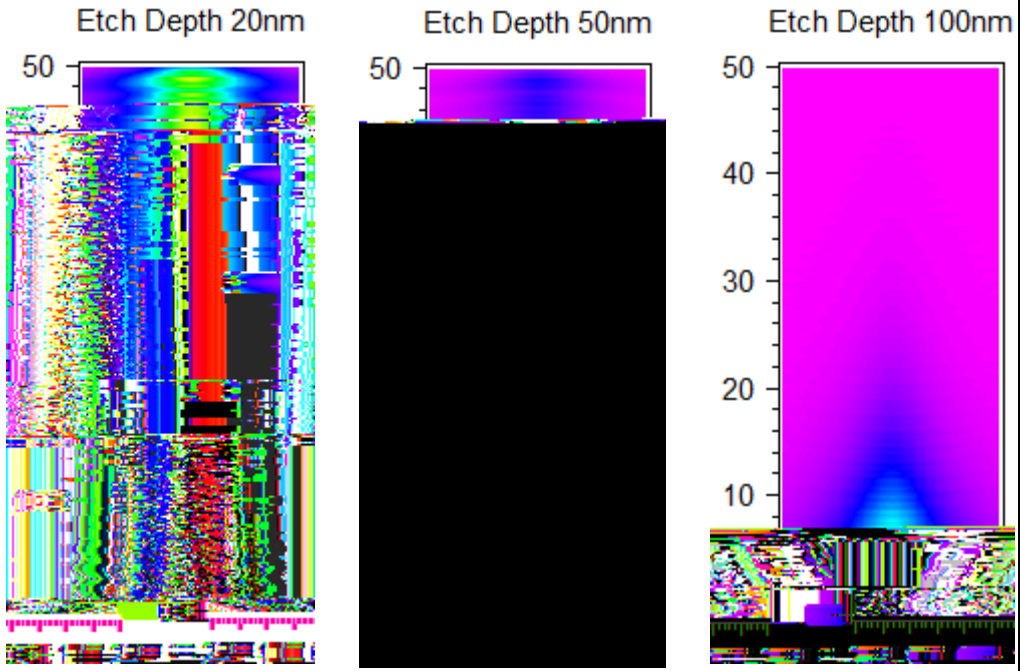


Van Acoleyen, Karel, Wim Bogaerts, and Roel Baets. "Two-dimensional dispersive off-chip beam scanner fabricated on silicon-on-insulator." *IEEE photonics technology letters* 23.17 (2011): 1270-1272.

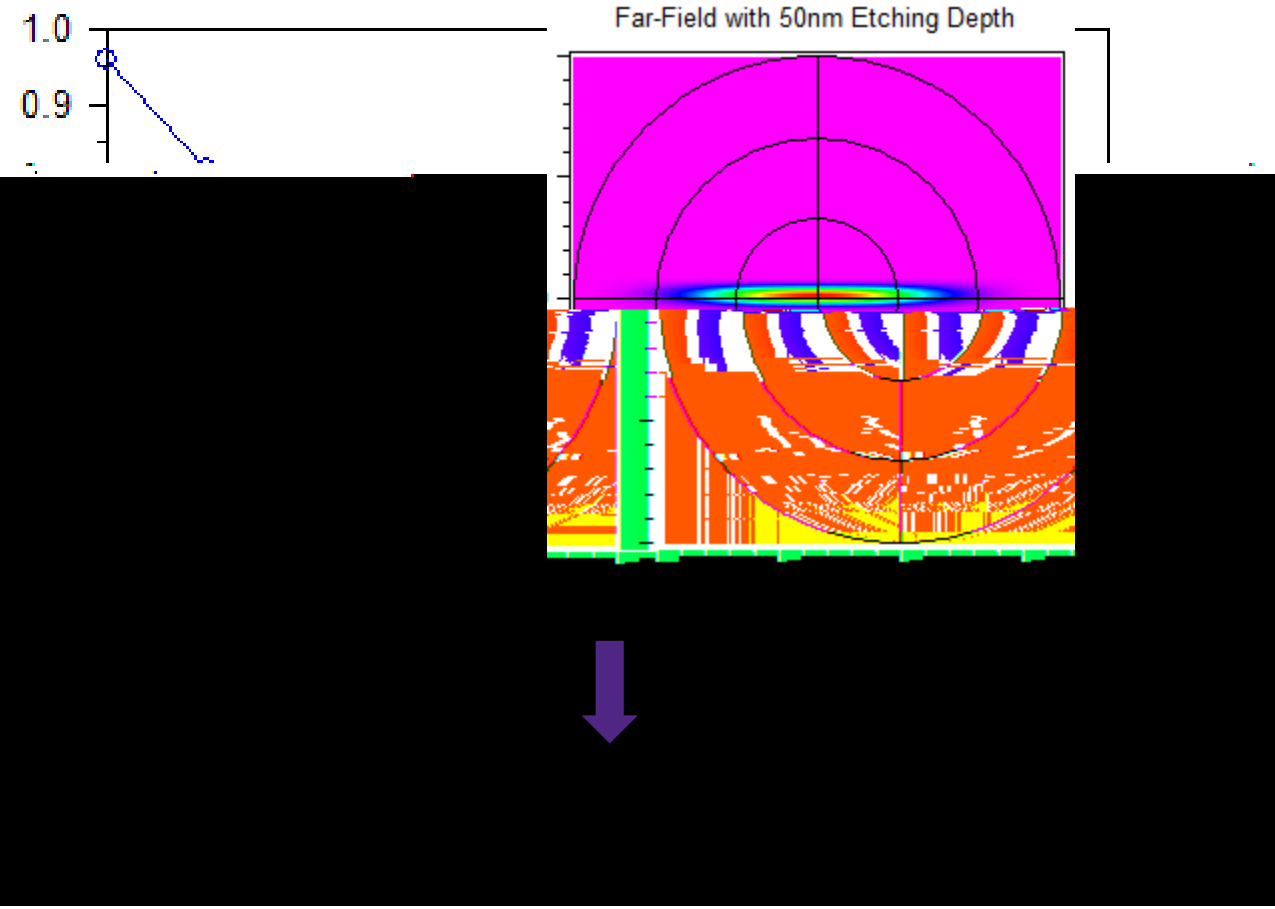
Etched Emitting Grating

Apodization is difficult for etched grating

- Emittance is always stronger at waveguide beginning
- The best designs should have even power emission, with nearly all power emitted out by the end of the waveguide

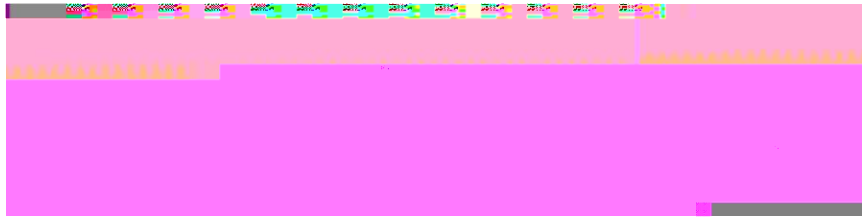


MOST scan of etching depth



Width Emitting Grating

Apodized grating can be used to emit light evenly and completely



Width function: ( )

Taper function: ( )

Parameters to be optimized

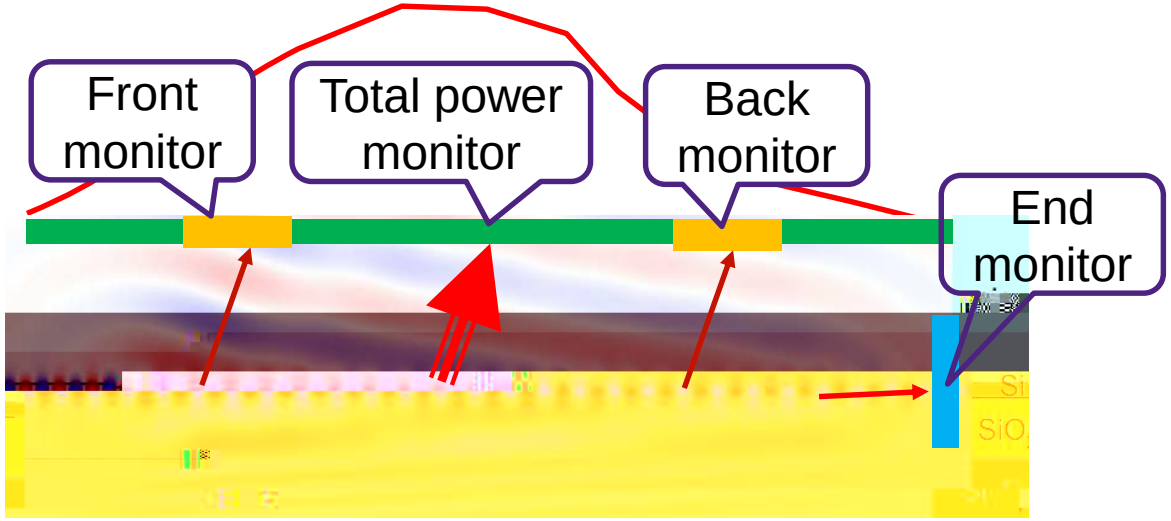
W, B, & P

Design Targets:

Maximize the emitted power

Minimize transmission through waveguide

Emitted power as uniform as possible

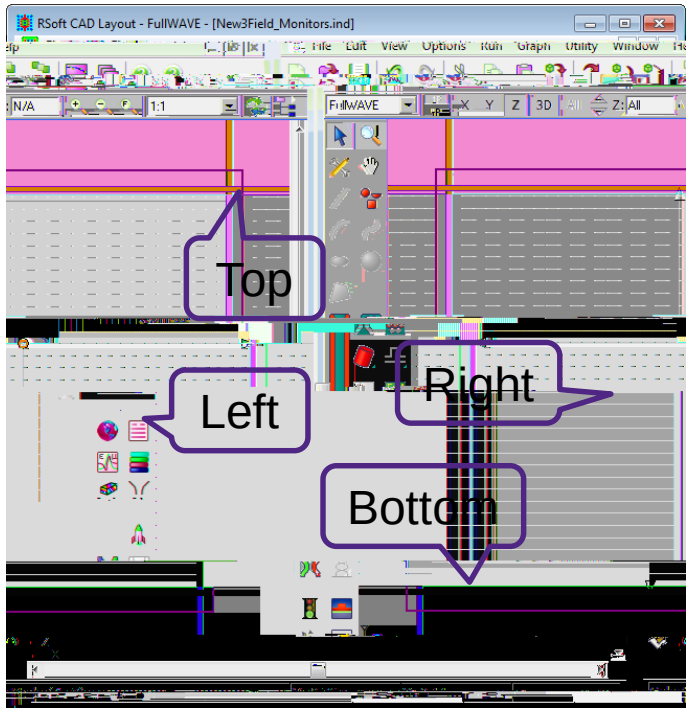


Target function:

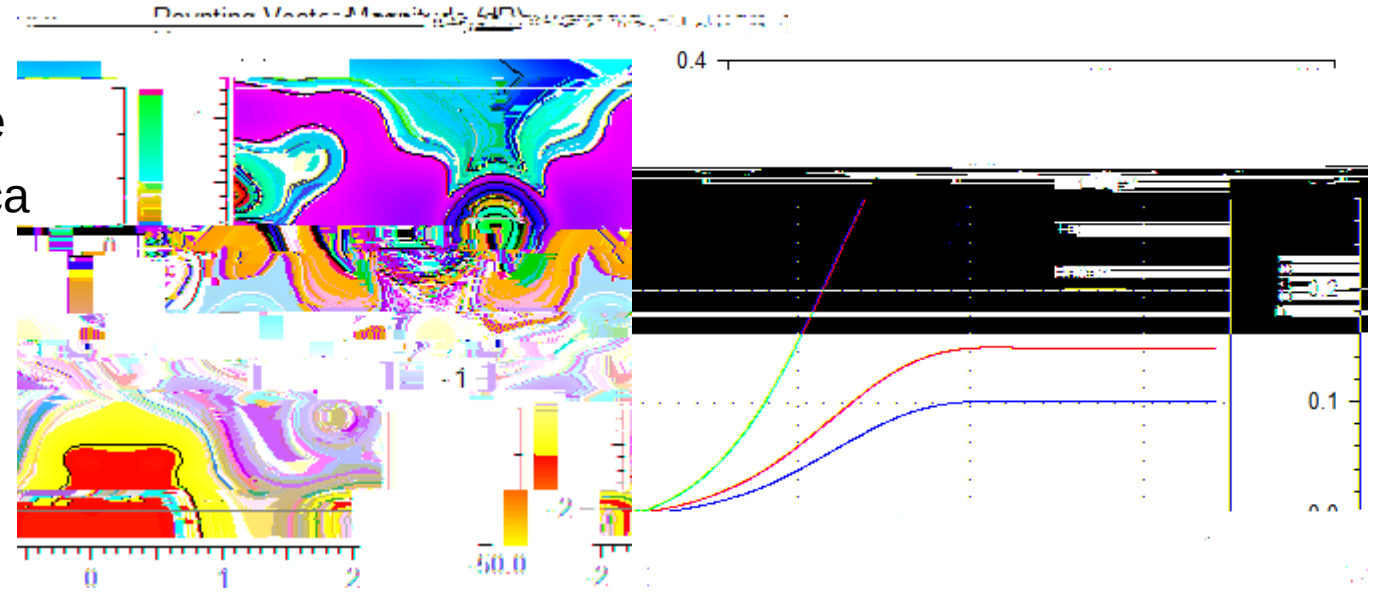
Power Flow in Grating Coupler

Four power monitors are placed at the boundaries to monitor the power flows

- Top: power emitted into air
- Bottom: power emitted into silicon substrate
- Left and right: power trapped inside the silica layer



Power flow



Most power is trapped inside silica layer

About 10% emitted into silicon substrate

Only about 15% power emitted into air

How to increase the extraction efficiency?

Textured surface, bottom mirror, etc

Multi-Channel Gratings

FullWAVE Simulation for Single Input

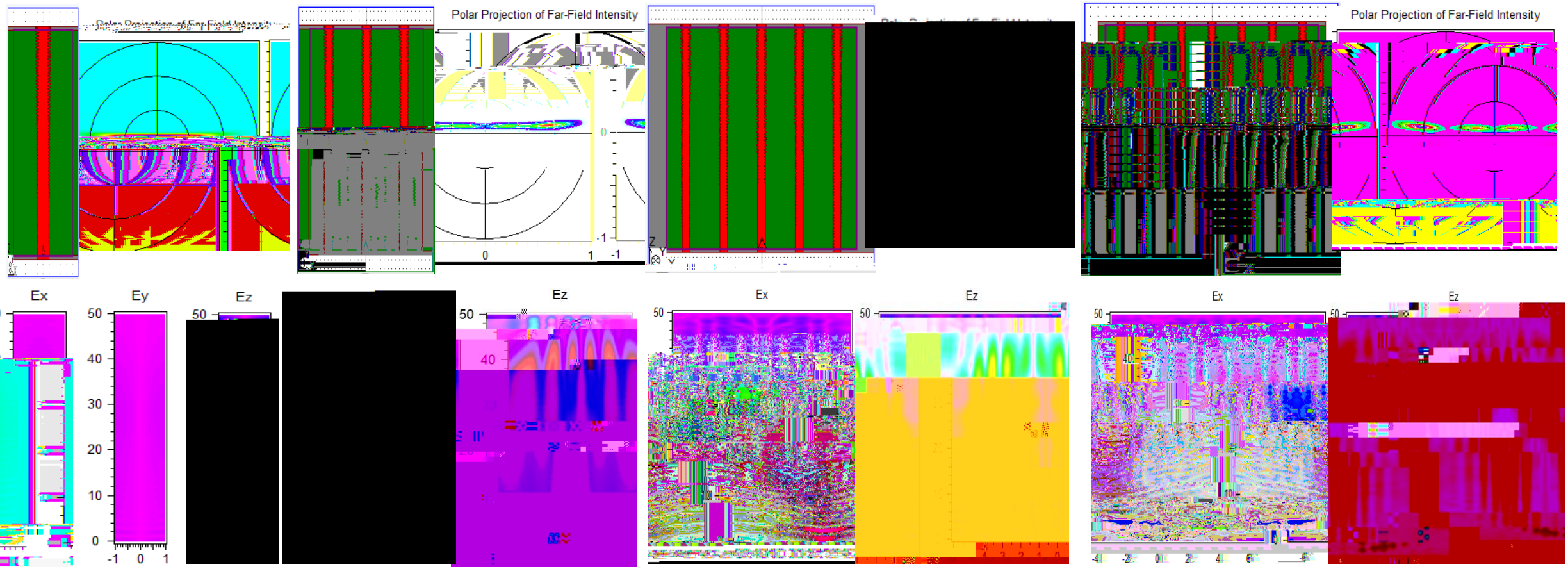
Convergence test

1 channel

3 channels

5 channels

7 channels

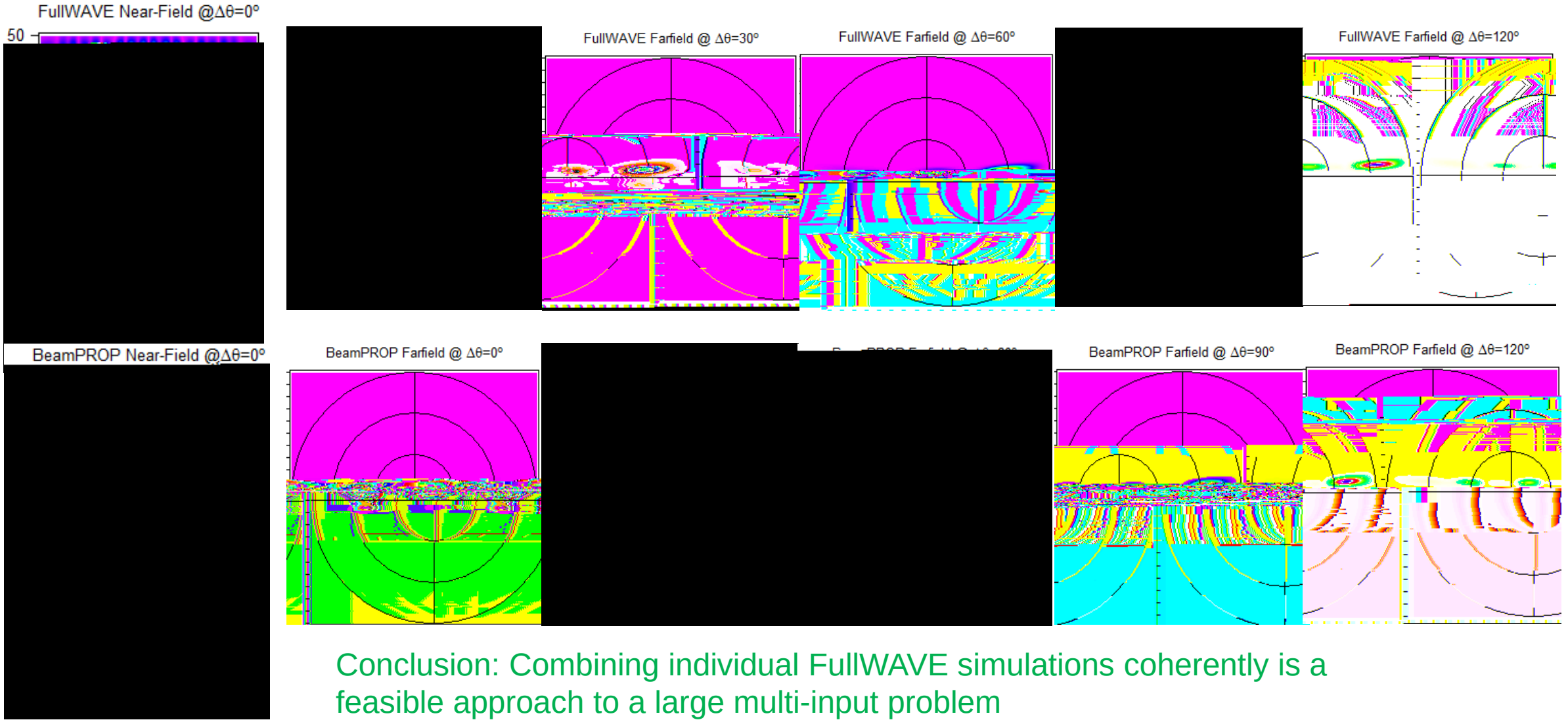


contribute to the far-field

5 channels gives reasonable converged results

Validation with 5 Inputs

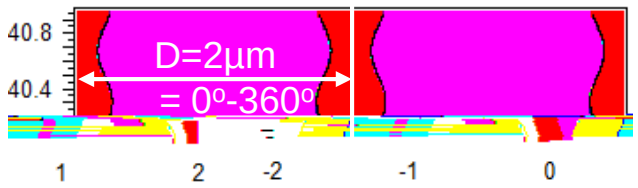
Comparison between FullWAVE and BeamPROP

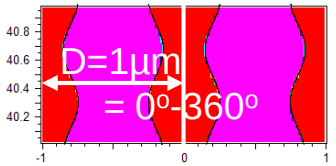


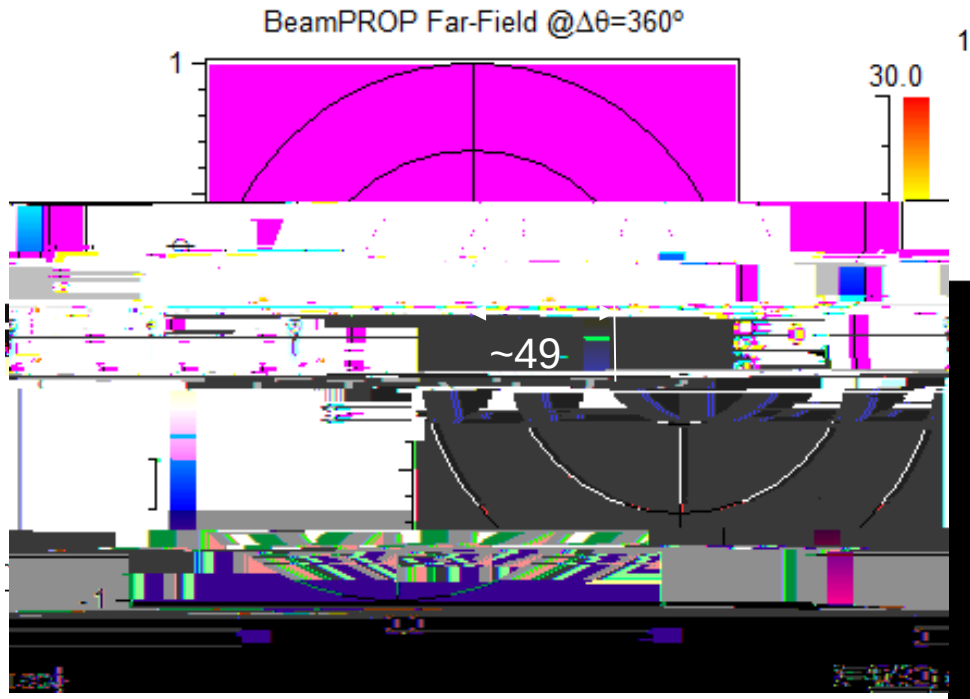
Conclusion: Combining individual FullWAVE simulations coherently is a feasible approach to a large multi-input problem

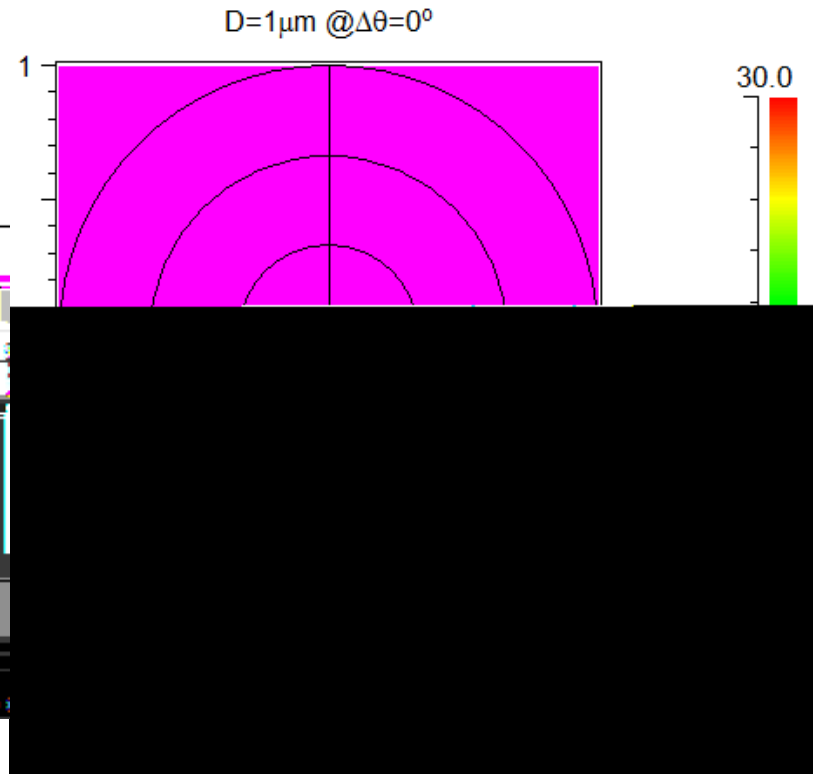
Lateral Beam Steering

Phase array tuning



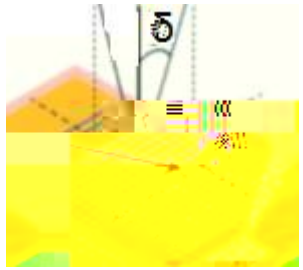


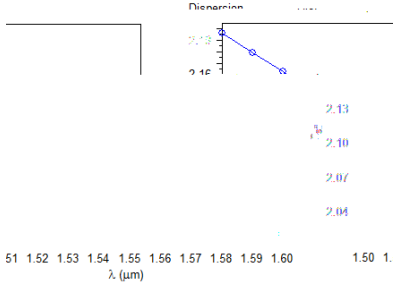




Vertical Beam Steering

Wavelength tuning





Beam steering angle:

$$\left(\frac{\qquad}{\qquad}\right)$$

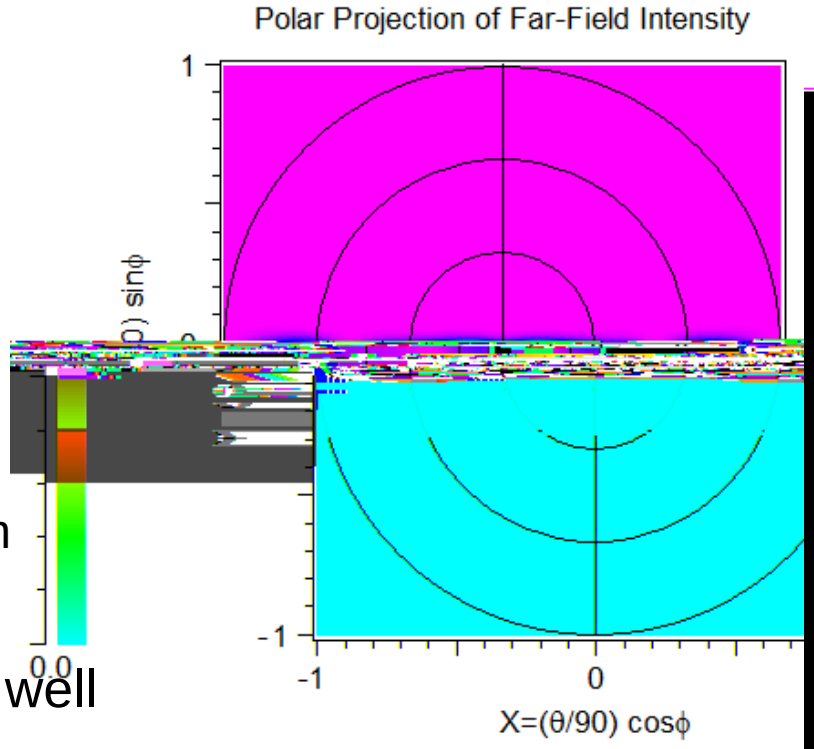
$$\frac{\qquad}{\qquad}$$

Dispersion is important!

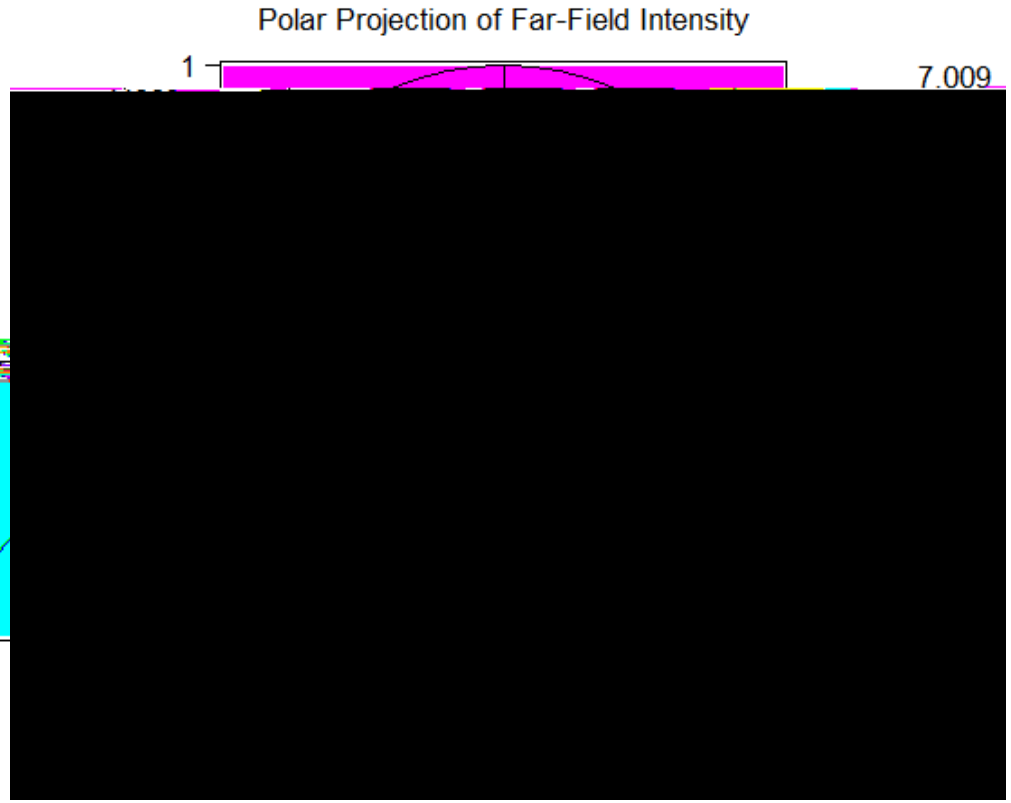
for =1.5~1.6μm

Simulation results agree well with theory

1-Channel



32-Channel



Conclusions

Recent LIDAR on-chip technology developments (Dec 2018)

60m Range with 5mW

- Edge output
- 8 Channels to 8 directions
- TX/RX integrated
- Limited by coherent length of the DFB laser
- No scan

Martin, Aude, Delphin Dodane, Luc Leviandier, Daniel Dolfi, Alan Naughton, Peter O'brien, Thijs Spuesens et al. "Photonic integrated circuit based FMCW coherent LiDAR." *Journal of Lightwave Technology* (2018).

Thank You